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The R&D objectives of this project are to increase the duty cycle and operation temperature of the far-JR p-Ge laser, to design and test a tunable frequency-stabilized laser for THz sensing and spectroscopy, and to obtain cryogen-free operation. All grant funds were allocated for the purchase of a state-of-the-an closed-cycle refrigerator system to be used in attaining the objectives. Support for other research expenses and salaries comes from the National Science Foundation and subcontracts on Zaubertek SBIR/STTR projects.

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**Widely tunable and high-duty terahertz p-Ge laser in a closed-cyle refrigerator**

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*University of Central Florida*

The R&D objectives of this project are to increase the duty cycle and operation temperature of the far-IR p-Ge laser, to design and test a tunable frequency-stabilized laser for THz sensing and spectroscopy, and to obtain cryogen-free operation. All grant funds were allocated for the purchase of a state-of-the-art closed-cycle refrigerator system to be used in attaining the objectives. Support for other research expenses and salaries comes from the National Science Foundation and subcontracts on Zaubertek SBIR/STTR projects.

The system purchased from Janis Research Co., Inc. was a Model SHI-4-15 Optical Cryostat system, a Model 331S Temperature controller, and a Model TP-70-2 Turbopumping station. The total cost was $64,530 plus shipping ($859.62). The small remainder of the $65,850 award was used to support installation expenses.

Important milestones in the purchase, installation, and testing are presented in Table 1. Photographs of the cooler and pump station are presented in Fig. 1

**Table 1. Project milestones.**

| Event | Date |
|---|---|
| Award letter | 4/2/01 |
| Contract start | 5/15/01 |
| UCF Account opened | 5/16/01 |
| Purchase order issued | 7/13/01 |
| Design details finalized | 9/9/01 |
| Received delivery of equipment | 1/10/02 |
| Began installation in new lab | 5/1/02 |
| Completed installation | 6/14/02 |
| First cooldown to 3 K | 7/10/02 |

This cooler was designed in Japan for medical MRI superconducting magnets. Hence, use of superconducting magnets to provide the field necessary for p-Ge laser operation is being explored. Small magnets, such as shown in Fig. 2, can apply uniform magnet fields up to 2 T with currents below 20 A. The variable field allows tuning over a wider range of laser emission wavelengths than would a permanent magnet assembly. The magnet shown is the same used for the first p-Ge laser in the United States [1]. A special cold plate with cold finger for the Ge crystal was built (Fig. 2).

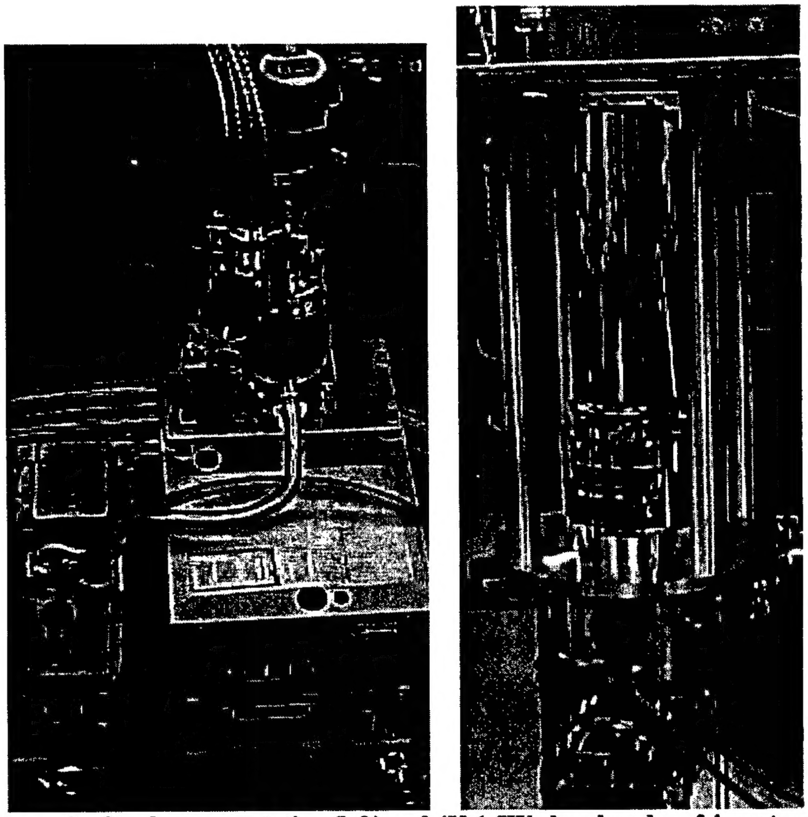

**Fig. 1. Photograph of turbo pump station (left) and 4K-1.5W closed cycle refrigerator (right). The cooler is inverted with cold head at the bottom and vacuum jacket at the top. There is an up-looking window to pass laser emission. The bottom of a down-looking 4K silicon composite bolometer (gold cryostat) is shown on the wooden platform.**

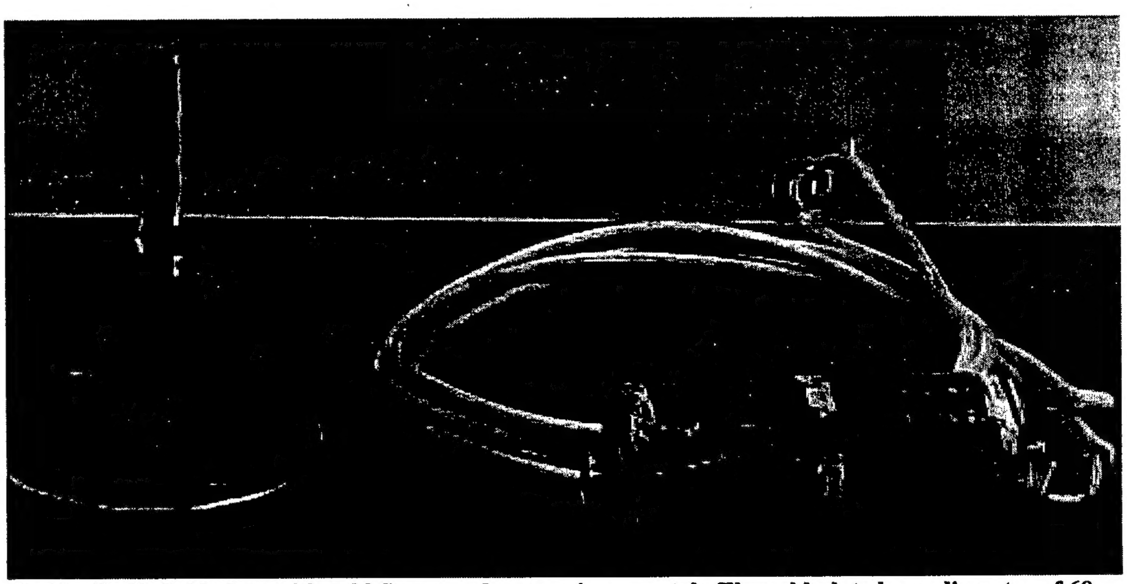

**Fig. 2. (Left) Cold plate with cold finger and germanium crystal. The cold plate has a diameter of 68 mm, which reveals the very large working area provided by the new cooler. (Right) Superconducting solenoid for use in the closed cycle refrigerator.**

Fig. 3 presents temperature vs. time curve with no thermal load on the cold plate (solid square symbols), where a temperature of 3 K is reached in about 40 minutes. Attaching the superconducting magnet and the cold finger with Ge crystal increases the cool down time to about 50 minutes. Then the final temperature reached was 4.5 K.

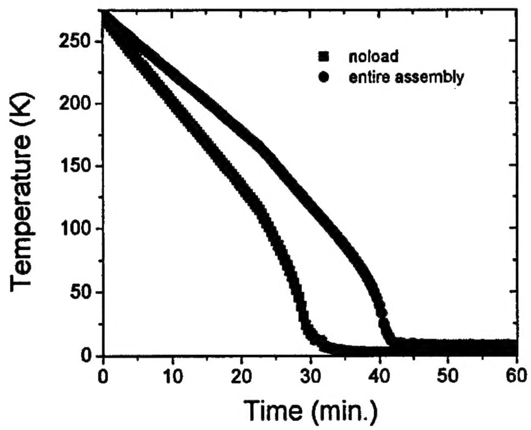


**Fig. 3. Temperature vs time for closed cycle cooler with no thermal load (squares) and with Fig. 2 load (circles). The final temperatures achieved were 3 and 5.7 K, respectively.**

A point to note in Fig. 2 is that the cold finger is attached only to a small portion of the Ge crystal. It was found that larger contact areas tended to break crystals because of the different thermal expansion coefficients of copper and germanium. Also, the new cold finger design is beveled to relieve stress at the point where the cold finger ends. The thermal conductivity of crystal germanium exceeds that of copper, so the rest of the laser crystal works as its own cold finger.

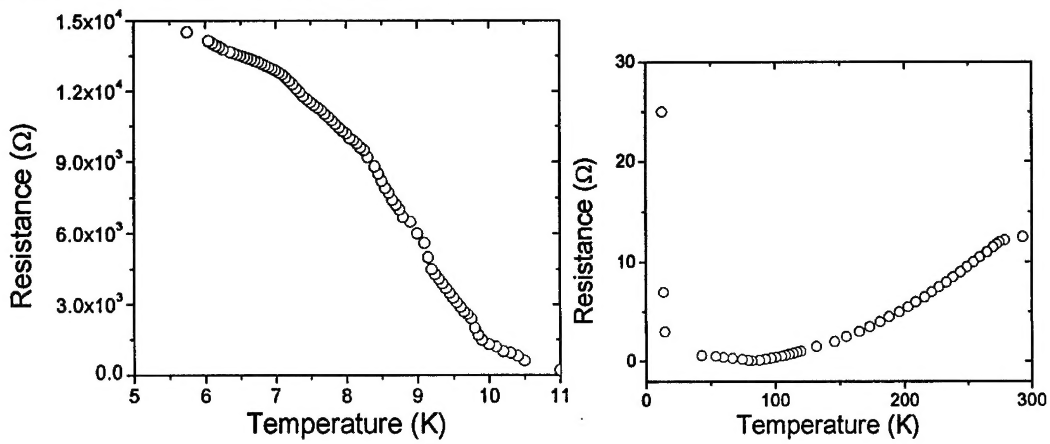


**Fig. 4 Test of short beveled cold finger design shown in Fig. 2. The crystal resistance is plotted as a function temperature for a sensor mounted on the cold finger. The superconducting magnet is also part of the cooler load.**

Fig. 4 shows the carrier freeze-out achieved, which begins in germanium at about 12 K. The final crystal resistance reached when the temperature sensor on the cold finger read 5.7 K was 15 kΩ. This is 3 times higher than our record achieved in our old CTI 10

K cooler without a magnet. It shows that the crystal is being effectively cooled with the new cold finger design and the cooling power is adequate to handle the large thermal mass of a superconcting solenoid. No laser results were available in time for this report, since we are still in the process of providing vacuum feedthroughs for magnet current.

During the period of this grant, our paper on laser experiments with high-field permanent magnet assemblies was completed, submitted, and accepted[2]. Advantages of permanent magnets over superconducting solenoids include compactness and freedom from current leads (which thermally load the cooler) and a current supply. The new cooler has a much larger cold plate than traditional 10 K coolers. This allows a substantial increase (more than a factor of 2) in the dimensions of permanent magnet assemblies over current art. A new assembly has been designed based on SmCo26H magnets with a remnant magnetization Br = 10.6 kG. Simulation of magnetic field lines in a cross section of the magnet is shown in Fig. 5. The air gap is 5.1 mm high by 12.7 mm wide. The maximum allowable assembly dimension is 6.8 cm, compared with 3.0 cm for the SmCo magnet tested and reported in [2]. The maximum field in the air gap is 0.97 T, compared with the 0.70 T field realized in [2]. This is important, because low magnetic-field thresholds occur only for the highest quality Ge laser material. The Fig. 5 magnet assembly will be manufactured for us by Magnet Sales, Inc.

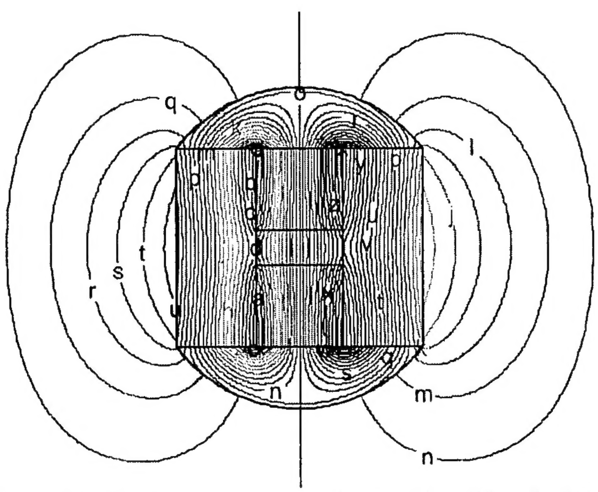

**Fig. 5. Cross section of large SmCo permanent magnet assembly with calculated magnetic field lines. The SmCo magnets are the rectangular pieces. The curved pieces are magnetic yokes. The maximum field in the air gap is 0.97 T.**

### References cited.

1. "Submillimeter p-Ge laser using a voigt-configured permanent magnet," Kijun Park, R. E. Peale, H. Weidner, and J. J. Kim, IEEE J. Quantum Electronics 32, 1203 (1996).
2. "High field p-Ge laser operation in permanent magnet assembly," C. J. Fredricksen, E. W. Nelson, A. V. Muarvjov, and R. E. Peale, Infrared Physics and Technology, in press (2002).